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Fluctuations in Čerenkov photon density in extensive air showers

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Abstract. In the absence of a standard source of γ-rays or hadrons of known energy one has to study the details of production of Čerenkov light at the observation level only through detailed simulation studies. Recently such studies have become all the more important in view of the various techniques resulting from such studies, to distinguish between γ - ray initiated events from those generated by much more abundant hadronic component of cosmic rays. We have carried our detailed simulation studies using the CORSIKA package in order to study the Cerenkov photon density fluctuations for 5 different energies in the range 50 GeV to 1000 GeV, at various core distances, both for γ - ray and proton primaries incident vertically at the top of the atmosphere. The density fluctuations are found to be significantly non-statistical. Also proton showers are found to show more fluctuations in shower size as well as density compared to γ - ray showers, at all energies. We have studied the contributions to fluctuations from various known processes, including Coulomb scattering of electrons, fluctuations in the height of first point of interaction and fluctuations in electron energy spectra. In principle, the differences in density fluctuations could be used to identify the nature of primary.

Key words : VHE γ - rays, extensive air showers, atmospheric Čerenkov technique, simulations, Čerenkov photon density fluctuations, CORSIKA.

1. Average lateral distributions of Čerenkov photons

CORSIKA package version 4.502 (Knapp and Heck, 1995) was used for simulation of air showers generated by γ - rays and protons, which are main constituents of cosmic rays. Air showers generated by monoenergetic γ - rays and protons incident vertically at the top of the atmosphere are studied in this paper. The Čerenkov radiation produced by the secondary charged particles within bandwidth of 300-500 nm is propagated to the observation level, which corresponds to Pachmarhi. Altitude and magnetic field appropriate for Pachmarhi (longitude : 78° 26′E; latitude : 22° 28′N and altitude : 1075 m amsl) location are taken. Wavelength dependent atmospheric attenuation of Čerenkov photons is not considered in this work.

Fig. 1 shows average lateral distribution of Čerenkov photon densities generated by γ - rays and protons of various energies. Lateral distributions produced by γ - rays show a characteristic hump at a distance of 135 m force core, with decreasing prominence with increasing energy. This hump is due to focussing of Čerenkov photons from large range of altitudes, where product of height and Čerenkov angle ($h\theta_c$) remains approximately constant (Rao and Sinha, 1988).

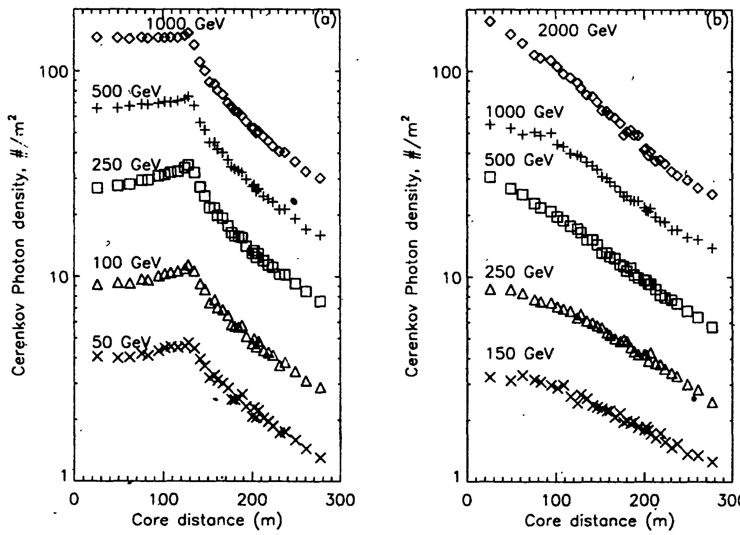

Figure 1. Average lateral distributions of Čerenkov photon densities resulting from extensive air showers initiated by vertically incident (a) γ - rays and (b) protons of various energies. Average of 400 showers are used for 50 GeV γ - rays and 150 GeV protons, 200 showers for 100 GeV γ - rays, 100 showers for the rest except for 1 TeV γ - rays and 2 TeV protons for which 50 showers were simulated.

2. Density fluctuations

Fig. 2 shows RMS shower to shower fluctuations in density of Čerenkov photons for γ - ray and proton primaries as a function of core distance. For both primaries fluctuations decrease

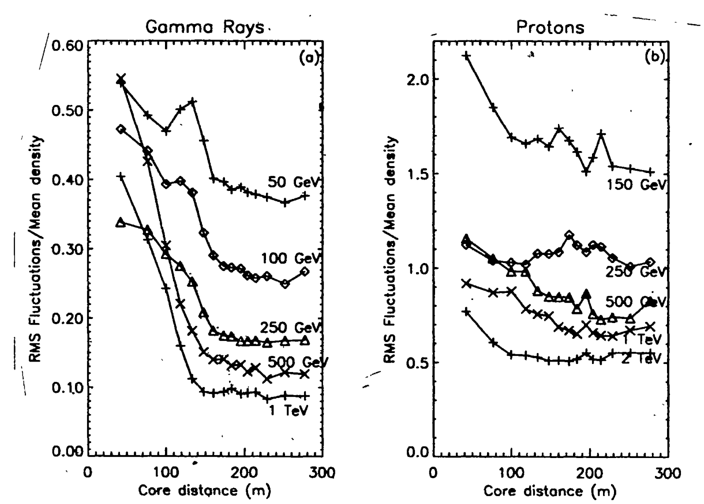

Figure 2. Ratios of non-statistical RMS values to the mean number of Čerenkov photon densities as a function of core distance at five different energies of primary (a) γ - rays and (b) protons. The relative fluctuations for proton primaries are higher and seem to decrease with increase in primary energies in cases of both protons and γ - rays.

with increasing energy. The relative fluctuations are higher for proton primaries. In case of γ - rays relative fluctuations are larger within hump. In both the cases, fluctuations are non-Poissonian and perhaps approach Poissonian value at large core distances. For details refer to Chitnis and Bhat, 1998.

3. Possible origin of fluctuations

3.1 Non-independent production processes

A single relativistic electron track can emit several Čerenkov photons which are generically related, consequently giving rise to non-Poissonian fluctuations at the observation level. Occasional local anomaly is caused by high energy electron track accentuating this effect.

3.2 Coulomb scattering of electrons

The Coulomb scattering of low energy electrons can lead to density fluctuations as the Čerenkov photons that are emitted by an electron could be diverted to a different location on the ground due to scattering of the parent electron in air. It results in Čerenkov photons reaching pre-hump and post-hump regions.

3.3 Fluctuations in the height of first interaction

The height of first interaction of a primary in the atmosphere that initiates the cascade fluctuates within one interaction length. The extent of fluctuation is decided by the radiation length in air (37.15 g cm^{-2}) in the case of γ - ray primaries and the interaction mean free path (70 g cm^{-2}) in the case of protons. These fluctuations lead to the fluctuations in the height of the shower maximum and hence in the total number of Čerenkov photons generated. We have estimated this effect using 500 showers of 100 GeV γ - ray and 250 GeV proton primaries. It is significant in the case of γ - ray primaries, resulting in an increase in RMS fluctuations in the total number Čerenkov photons from 3% to 5.2%, compared to the case where height of first interaction is fixed. In the case of proton primaries, however, this effect is found to be negligible, indicating that the contributions from other processes dominate.

3.4 Electron number fluctuations

Fluctuations in the number of Čerenkov photons at a given height in the atmosphere can be attributed to those in the number of electrons, which in turn owe their origin to the production kinematics.

3.5 Electron energy spectra at various atmospheric depths

Another important contribution to fluctuations comes from the fluctuations in the electron energy and their spectra during the shower development. The energy spectra of electrons at various atmospheric depths are found to be similar in shape, however the average energy and number of surviving electrons after the shower maximum is relatively higher for proton primaries.

Larger fluctuations seen in the case of proton primaries are traced back to the kinematics of showers. In this case, the source of electrons is pair production by γ - rays which are decay products of π^0 mesons produced in hadronic interaction. Also charged pions can decay into muons which in turn decay to electrons. The fluctuations in the multiplicities of the pion secondaries and their energy spectra combined with the fluctuations due to larger hadron interaction mean free path lead to larger electron number fluctuations in case of proton primaries.

Summary

Here we have carried out systematic study of density fluctuations as a function of core distance for various energies of γ - ray and proton primaries. This study is important in planning observations of VHE γ - ray sources. Density fluctuations are found to be significantly non-statistical for both γ - ray and proton primaries, approaching Poissonian values at large core distances. We have investigated various known sources of fluctuations and tried to evaluate their relative contributions. Average electron energies and their spectra at different atmospheric levels during the shower development are found to be similar in the case of proton and γ - ray primaries. Whereas number of electrons at various depths of shower development is found to vary much more for protons compared to γ - rays. The effect of variation in the first point of interaction on density fluctuations is found to be significant only in the case of γ - ray primaries. Contribution to the fluctuations also comes form Coulomb scattering of low energy fluctuations is found to be significant only in the case of γ - ray primaries. Contribution to the fluctuations also comes from Coulomb scattering of low energy electrons past the shower maximum and the intrinsic correlation between the photons emitted by a single electron.

Differences in the density fluctuations in showers produced by γ - ray and proton primaries can be used to reject cosmic ray showers in VHE γ - ray observations. In this respect, studies of intra-shower fluctuations are more useful than shower to shower fluctuations. We have studied the former for γ - ray and proton primaries in some detail even though the bulk of the paper deals with the latter. Relative fluctuations are found to be higher by a factor of two for protons compared to γ - rays (Chitnis and Bhat, 1998). These can be studied experimentally and can provide useful parameter to identify the nature of the primary.

References

Chitnis V. R., Bhat P. N., 1998, Astroparticle Physics, 9. 45.

Knapp J., Heck D., 1995, EAS Simulation with CORSIKA, V4.502 : A User's Manual.

Rao M. V. S., Sinha S., 1988, Phys. G. Nucl. Phys., 14, 811.